SESSION 1: Pelagic fish

H. Gjøsæter[1] and N.G. Ushakov[2]: Capelin in the Barents Sea

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Abstract

The report discusses the past and present management of the Barents Sea capelin stock. It also provides a short recapitulation of stock characteristics and the history of the stock and fishery.

Stock characteristics

This synopsis of capelin biology and history of the stock and its exploitation is partly taken from Gjøsæter (1998), where a more thorough discussion of capelin biology and exploitation, and references to the original literature, may be found. A thorough description of capelin with numerous references covering the period up to 1984 may be found in the Proceedings of the Second Soviet-Norwegian Symposium (Gjøsæter, 1985). Another important sources of information devoted to capelin of the northern hemisphere (with about one third of the papers dealing with Barents Sea capelin) is found in the proceedings of an ICES symposium, held in Reykjavik, 2001 (Hollingworth, 2002). A great deal of information on capelin (in Russian) can be also found in PINRO Press publications (Luka *et al.*, 1991; Prokhorov, 1965).

This capelin stock is confined to the Barents Sea, and on the basis of current knowledge there are no signs of exchange of individuals between this and other capelin stocks. Its distribution varies with season, and migrations are extensive, (Figure 1). Capelin have demersal eggs, and their spawning areas are limited to sandy bottom at depths of about 15-60m. The main spawning takes place along the coast of Norway and Russia from about 15°E to 35°E, but sporadic spawning further east has been observed (Luka *at al.*, 1991). The whole area between these longitudes is not utilized every year, and spawning may be concentrated in western, central or eastern areas.

The eggs hatch after about one month, and the fry are carried by the prevailing currents north and east into the central and eastern parts of the Barents Sea. The larvae normally metamorphose during spring in their second year of life, and they gradually adopt the seasonal migration pattern characteristic of adult capelin. During the feeding season, from late spring to late autumn, distribution gradually shifts northward, reflecting the peak of zooplankton production. Production of phytoplankton and zooplankton starts in the southern parts of the sea, in particular on the coastal banks, and as the water masses stabilize it moves further north. The ice, covering the waters north of the polar front in the winter, melts during the summer, and a plankton bloom tends to follow the receding ice edge. The capelin migrate northwards and into the previously ice covered areas, utilizing the rich zooplankton production there during late summer and autumn. When temperatures fall in late autumn and the ice forms again in the areas dominated by Arctic water in the north, the capelin move southwards, to winter in the ice-free areas south of the polar front. From these wintering areas, the maturing part of the stock migrates to the coast to spawn in spring. Large-scale changes in the water temperature generate a significant displacement of the distribution area of capelin, which thus change their pattern of migration (Ozhigin and Luka, 1985). The capelin becomes sexually mature at a length about 14 cm. Depending on growth rates, this change occurs at an age of three, four or five.

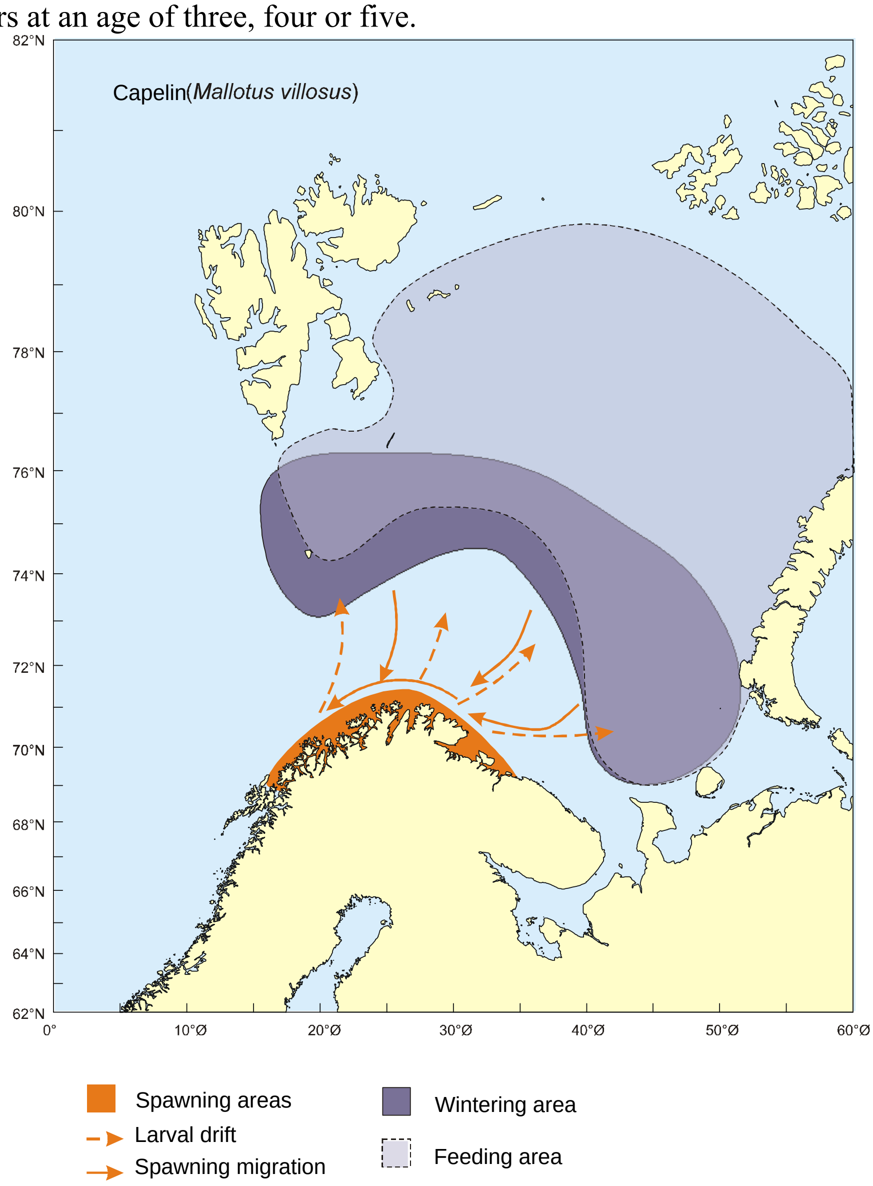

Figure 1. Distribution and migrations of the Barents Sea capelin stock

Capelin are mostly semelparous, i.e. they spawn only once and then die. Some individuals may survive the spawning, but since capelin are heavily preyed upon by cod, their main predator, during the spawning season, very few spent capelin survive to spawn for a second time. In the period 1984-2001, it has been estimated that cod consume from 0.2 to 3.0 million tonnes of capelin annually, depending on the sizes of the cod and capelin stocks (Figure 2). Apart from the three collapse periods (see below), the amount of capelin consumed annually by cod has been more than one million tonnes. Other fish predators include haddock, Greenland shark, Greenland halibut and Esmarks eelpout, thorny skate, long rough dab, deep sea redfish and various rockfishes. Other important predators are seals (mainly harp seals) and whales (mainly minke and humpback whales). Seabirds consume some capelin; their main avian predators are the common guillemot and puffin. There is lack of quantitative information about the annual consumption of capelin by these predators, but based on the estimates that have been published there are reasons to believe that the amount of capelin taken annually by predators other than cod may amount to less than one million tonnes. A special kind of predation is that which takes place when young herring feed on capelin larvae in summer and autumn (Huse, 1994; Huse and Toresen, 2000). This is thought to be one of the major mechanisms behind the recruitment failures that have been observed in the capelin stock (Hamre, 1985; 1988; 1991; 1994; Gjøsæter and Bogstad, 1998; Ushakov and Shamrai, 1995). These recruitment failures were the direct reason for the stock collapses referred to above (Gjøsæter, 1995; 1998).

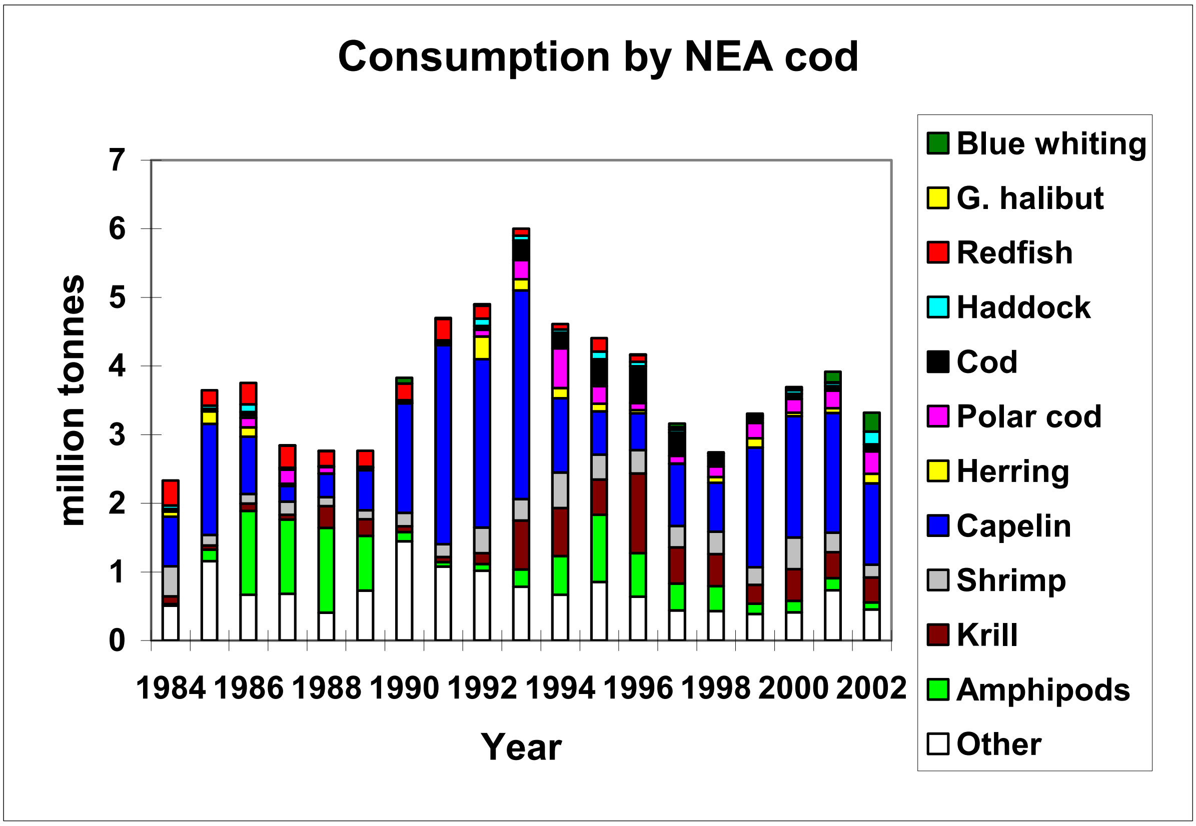

Figure 2. Annual consumption by cod based on the joint Norwegian-Russian cod stomach database (Mehl and Yaragina 1992, annually updated in the reports from the ICES Arctic Fisheries Working Group and the Northern Pelagic and Blue Whiting Fisheries Working Group).

The capelin is a specialized plankton feeder and is the most important planktivorous fish in the Barents Sea. Other fish at the same trophic level is herring and partly Polar cod, in addition to several species during their 0-group stages. Since herring, when present in the Barents Sea, are confined to the southern parts of the area, there is not much distributional overlap between these two species. The polar cod is not a specialized plankton feeder, and hence primarily consumes larger zooplankton forms. Due to their semipelagic way of life, adult polar cod mostly feed at near-bottom depths, while capelin may feed throughout the water column. Polar cod are distributed in Arctic and mixed water masses, while capelin feed in both Atlantic and Arctic waters. There is thus potential feeding competition between capelin and polar cod (Panasenko, 1990), and to a lesser extent between capelin and herring. Various 0-group fishes may overlap with capelin and act as competitors for food during the late summer and autumn. The practical implications of such competition from one year to the next are largely unknown.

The size of the capelin stock has been seen to vary widely in the thirty-year period during which the stock has been monitored (Figure 3). Based on indirect knowledge about stock dynamics in the Barents Sea, there are reasons to believe that fluctuations in capelin stocks are inherent in the ecological processes in the area, and should be looked upon more as natural perturbations than man-induced instability in the ecosystem. However, there is firm evidence that the exploitation of capelin and of its predator stocks may have affected the magnitude and length of periods when the capelin stock has been at low levels.

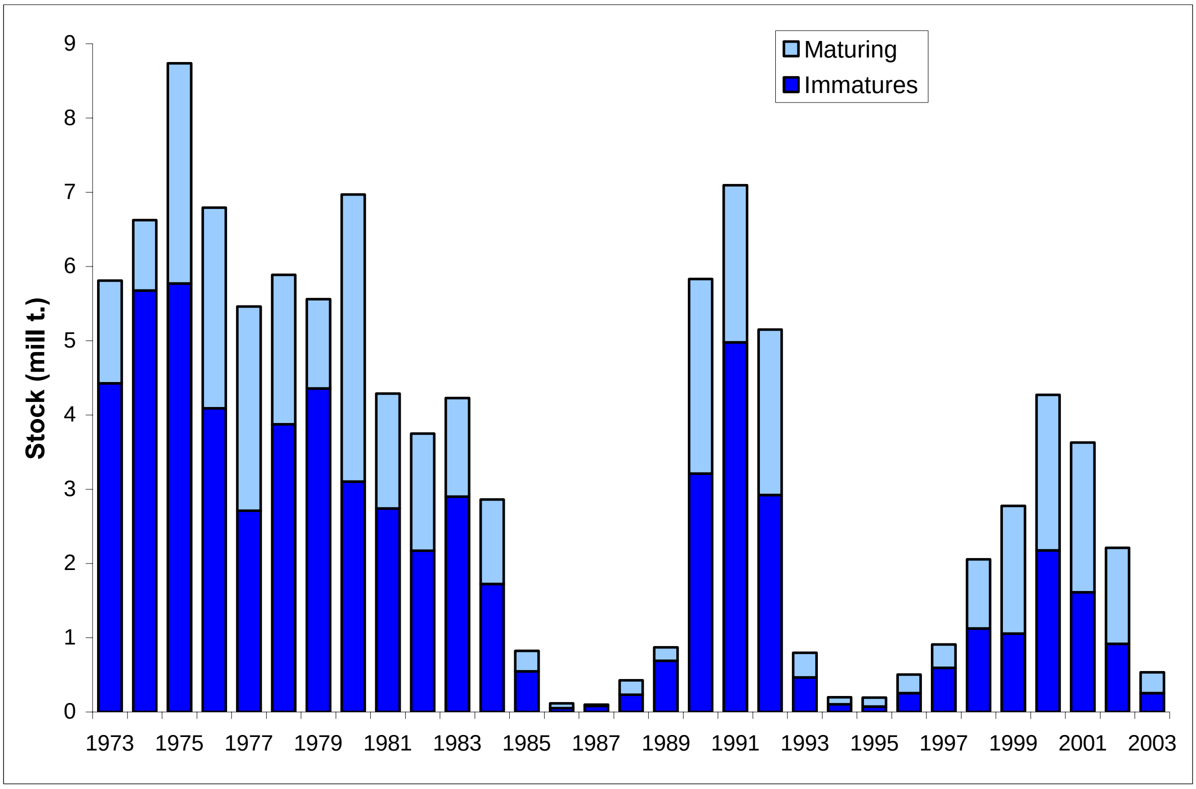

Figure 3. Stock history of the Barents Sea capelin. Acoustic estimates during the annual joint Norwegian-Russian acoustic survey in autumn.

The monitored history of capelin stock size is characterized by three stock collapses (according to the definition introduced by Gjøsæter et al. (2002), this is when the stock size is below one million tonnes when measured in autumn), in the periods 1985-1989, in 1993-1997, and from 2003. Except during these periods the stock size has mostly been at a level of 3-6 million tonnes, and peaked in 1975 and 1991, when the stock was measured acoustically to be above seven million tonnes.

History of the capelin fishery

The Norwegian capelin fishery has a long history. The capelin were originally fished with beach seines on the coast of Finnmark during the spawning season, and mainly used as bait, fertiliser or animal food. From 1916 on, capelin were used for meal and oil production in Finnmark, but it was not until the 1930s that a fishery for industrial purposes became important. Since the late 1950s, following the decline in abundance of the stock of Norwegian spring spawning herring, the purse seine fleet increasingly focused its efforts on the capelin, and by 1957 purse-seiners had totally replaced the beach-seines. From 1961 onwards, pelagic trawls were also employed in the fishery, which at that time took place in the spawning season only. Beginning in 1968, a summer fishery rapidly developed in the open sea.

The Russian (former Soviet) capelin fishery also has long traditions, and was carried out using beach seines and nets along the Kola coast during the spawning season. Starting in the early 1960s, purse seines and pelagic trawls replaced the beach seines and the fishery expanded into the open areas of the Barents Sea in the 1970s.

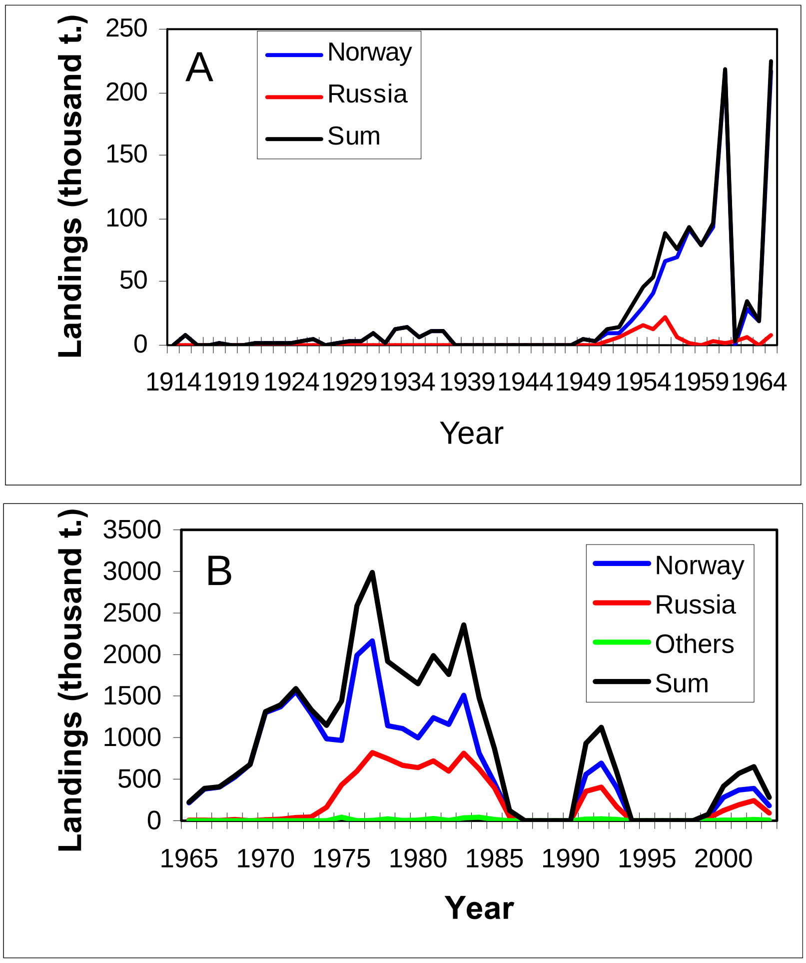

Figure 4. Catch history of the Barents Sea capelin. Panel A: 1914-1965. Panel B: 1965-2003. (Gjøsæter, 1998; updated based on reports of the ICES Northern Pelagic and Blue Whiting Fisheries Working Group)

In the 1970s, the capelin fishery became of prime importance to Norwegian and Russian fleets, with nearly three million tonnes being landed in 1977. Since then, the three stock collapses have resulted in the capelin fisheries becoming more variable. Furthermore, the fishery was closed from 1987-1990 and again from 1994 to 1998. Figures 4A and B present catch statistics for 1914 to 1965 and 1965 to 2003. Landings increased sharply in the 1950s, but declined almost to zero in 1962-1964. From 1965 onwards, the increase in catch continued until the early 1970s. From 1972 to 1983 Norwegian landings fluctuated around 1.5 million tonnes, while Russian landings increased and brought total annual landings up to 2-3 million tonnes. From 1984, catches decreased, partly because of quota restrictions, but primarily because the stock collapsed. The fishery was closed from autumn 1986 until autumn 1990, and the catches taken from the recovered stock in 1991-1993 were relatively small compared to the period 1970-1985. The fishery was closed again in spring 1994, when a new stock collapse was evident, but was opened on a recovered stock in 1999. In recent years, the fishery has been restricted to a winter fishery only, and about 500 000 tonnes have been taken annually. From 2004, the fishery was again closed.

History of the management system

This synopsis is partly taken from Gjøsæter *et al.*, 2002, where a more detailed presentation of the management of the Barents Sea capelin and references to the original literature can be found. Management goals in the period prior to the first stock collapse were rather *ad hoc*. Only in two years, 1974 and 1978, was a national catch quota introduced in the Norwegian fishery. These catch quotas were introduced on the basis of the results of the acoustic stock measurements, because a reduction in the mature component of the stock was observed, and it was felt that a fishery on this component might endanger recruitment. No attempts were made to evaluate the consequences of an alternative management policy due to lack of basic knowledge of the stock-recruitment relationship, natural mortality, and consistency of the acoustic stock measurements (Hamre, 1985).

In 1978, the Soviet/Norwegian Fishery Commission requested scientists from both countries to evaluate the state of the stock and submit proposals for necessary joint management actions. Two meetings of scientists were held in 1978, resulting in the following agreement:

A total allowable catch (TAC) assessment of capelin should be based on acoustic stock measurements carried out jointly in the autumn, the assessment period should cover the winter and subsequent autumn fishery and the assessment should aim at maintaining a minimum spawning stock of 500 000 tonnes. The strategy was based on a rough evaluation of the curve of spawning stock biomass vs. recruitment: for spawning stocks below this limit the risk of poor recruitment apparently grew.

During this period, Sigurd Tjelmeland developed the model “Capelin” (Tjelmeland, 1985), as an aid to performing the assessment outlined above.

The model was also augmented with a recruitment module, which enabled long-term prognoses to be made to study maximum sustainable yield, etc. Using this model Hamre and Tjelmeland (1982) analysed the yield functions for various fishing patterns and allocations of the total catch on the autumn and winter fisheries. They introduced the new concept “M-output biomass”, which denoted the production of capelin available for predators. One of their conclusions was that the maximum sustainable yield of capelin would be reached with a spawning stock biomass of about 400 000 tonnes. Another observation was that fishing during the autumn would maximize the yield but lower the M-output biomass considerably. In a multispecies context, winter fishing would therefore be preferable to autumn fishing. Based on those analyses, the recommended minimum spawning stock level was kept at 500 000 tonnes, but it was recommended that most catches should be taken during the winter season.

During the period 1986 to 1990, a fishing ban was recommended because, even in the absence of any fishing, the spawning stock size was estimated to be below the 500 000 tonnes limit.

After the stock collapse during 1985-1989, it was realised that the assessment model used previously was inadequate. First of all, the method for estimating the natural mortality of the mature capelin during the winter months was too simplistic (Tjelmeland and Bogstad, 1994). In 1984, a joint Norwegian/Russian cod (*Gadus morhua* L.) stomach sampling programme was launched (Mehl and Yaragina, 1992), and it was found that capelin made up a considerable part of the diet of cod during the winter. Furthermore, cod is the most important predator on capelin. A project that had the aim of constructing a multispecies model (MULTSPEC) including the principal fish and sea mammal stocks in the Barents Sea was launched (Tjelmeland and Bogstad, 1998). This model, however, was rather complex and data-intensive, and was never used in its full version as a stock assessment tool for quota regulation purposes. An attempt was made to utilize the data in the stomach content database to estimate the amount of capelin consumed by cod (Bogstad and Gjøsæter, 1994), and to use this as an estimate of the natural mortality of maturing capelin during winter. This was a first attempt to include the influence of other species in the assessment of capelin. Based on a combination of the capelin model and some *ad hoc* methods related to the calculation of presumed capelin consumption by cod, TAC recommendations were made from 1991 to 1993. However, it was soon realized that the large stock size in this period was based on one single year class, the 1989 year class. From 1992 onwards, a new period of recruitment failures was apparent, the stock dwindled and once again a fishing ban was recommended and introduced (Gjøsæter, 1998).

The development of assessment methods capable of taking the influence of other fish stocks into account continued during and after the second capelin stock collapse. This process included continuing work on the inclusion of the influence of the cod stock on capelin mortality during the winter (Bogstad and Gjøsæter, 2001). However, since the recruitment failure of the capelin, resulting in the two stock collapses, was partly attributable to the stock of young herring appearing infrequently in the Barents Sea, focus was now also put on including the effect of herring (Gjøsæter and Bogstad, 1998). During this period, the single-species model capelin was abandoned in favour of a model in the MULTSPEC family of models: the Bifrost (former CapSex) model (Gjøsæter *et al.*, 2002). This model is also a multispecies model but, unlike the MULTSPEC model, it has no geographical resolution. For TAC-calculations, it is combined with the spreadsheet model CapTool implemented in the @RISK add-on to MS Excel. The parameters of the model are estimated using Bifrost, and this model is used to construct replicate parameter files for the future stochastic development of the stocks. These replicate files are fed into CapTool, which, for given catch quotas, gives probability functions for capelin stock development. This pair of models has been used to calculate TACs since 1998 until the present, but has continuously been updated and augmented during this period. These models introduce a probabilistic assessment . Although it is based on multispecies considerations, this is still a single species assessment, since neither the effect of fishing on the herring stock (affecting the capelin recruitment) nor the effect on the growth of cod of fishing on the capelin stock is quantified.

Current managements strategy

Once the assessment of capelin had been made probabilistic, ACFM started to propose for the Norwegian-Russian Fishery Commission a management strategy with the following elements: A B_{lim} of 200 000 tonnes, only fishing on the prespawning fish in spring, and an escape strategy with a risk of 5% that the spawning stock size would be less than B_{lim}. In most years this strategy is somewhat more cautious than the previous strategy used when the assessment gave a deterministic prognosis for the spawning stock size; to let 500 000 t spawn. This is because in most years, the uncertainty in the assessment is so large that when the fifth percentile is at 200 000 t, the median of the probability distribution, comparable to the old deterministic estimate, is greater than 500 000 t. ACFM considers this strategy to be in accordance with the precautionary approach. During its meeting in November 2002 the Joint Norwegian-Russian Fishery Commission adopted this strategy and stated in the protocol: *"The Parties agreed on a exploitation strategy for capelin where the TAC is not set higher than that, with 95% probability, at least 200 000 tonnes of capelin are allowed to spawn. The Parties decided to open the fishery in the winter months from 1 January to 30 April in 2003"*. ACFM will therefore continue to present its advice on a TAC for Barents Sea capelin on this management strategy.

Throughout the whole period of capelin management by the Joint Norwegian-Russian Fishery Commission (agreed in 1978), the TAC has been allocated to Norway and Russia in the proportion 60/40. In 1978, a rule defining a closed season from 1 May to 14 August was introduced, and the catch of juvenile capelin below 11 cm was limited to 15 % by weight. In 1981, the proportion of the allowable catch of fish below 11 cm was reduced to 10 %, and in 1984, the opening date of the autumn fishery was postponed to 1 September. In 1981, a minimum mesh size of 16 mm in capelin nets (both trawls and purse seines) was introduced. In recent years, the mesh size regulations and the minimum landing size regulations have remained the same, but the fishing season has been restricted to January until April. Only areas south of 74°N have been open to the fishery, in order to avoid catching juveniles. During the fishing season, the parties may close the fishery in particular areas south of this latitude, if problems with by-catches of herring or other species are detected in certain areas.

Enhancements to the current management strategy

The assessment group that meets after the capelin survey every autumn has expressed concern that, since it is known that the presence of young herring in the Barents Sea may seriously hamper capelin recruitment, this should be taken into consideration when setting the TAC, so that in "herring years" the amount of spawners should be kept higher, in order to counteract the negative influence of the herring. The assessment group has suggested that a variable B_{lim} could be used for this purpose, since the interesting quantity here is not the spawning stock as such, but the recruitment that will result from its spawning. The assessment group has also suggested that a target reference point should be sought, since the recruitment may gain from a higher spawning stock than that resulting from the present target escape strategy. ACFM has agreed to these ideas but has maintained that, so far, the basis for suggesting a variable B_{lim} or a B_{target} is too uncertain.

In addition, further work needs to be done with the aim of moving from a spawning stock biomass to a quantity that takes into account the quality and amount of eggs spawned. On the basis of population fecundity analysis, and taking into account the fact that the spawning stock size should be large enough to create sufficient recruitment even in years with poor survival conditions for the larvae, a proposal has been put forward that nearly one million tonnes of spawning stock biomass should be saved (Ushakov and Tereshchenko, 1992; Tereshchenko, 2002). This estimate is somewhat higher than that corresponding to a B_{lim} of 200 000 tonnes. The spawning stock biomass corresponding to a preferred level of population fecundity will vary from year to year due to changes in the age and size structure of the stock. To date, ICES has not considered this proposal.

Even with these enhancements. the management strategy will still be a single species strategy, and as such, would be inadequate in the long run. The ultimate goal should be to manage the stock complex found in the Barents Sea together, so that the amount taken from the stocks of say, capelin, cod, shrimp, seals and whales would be based on their effects on each other and also on their respective economic values. There is a long way to go until we are there, but on the other hand: the Barents Sea ecosystem is one of the best known in the world as far as multispecies effects are concerned, and as such, would be the right place to start experimenting with a more integrated management system.

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